

(SUBSTITUTE SPECIFICATION)

TITLE OF THE INVENTION

Two-shaft vacuum pump

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to a two-shaft vacuum pump.

Description of related art

A rolling piston pump, also referred to as Roots pump, is a typical two-shaft vacuum pump. Both shafts of the Roots pump comprise a rolling piston which rolls off without contacting each other. One of the two shafts (i.e., the drive shaft) is driven by an electric drive motor, while the other shaft is synchronized with the drive shaft by means of a gear. During a pumping operation, the rolling pistons are strongly heated due to a gas compression.

In practice, generally only asynchronous motors are used as drive motors. A motor rotor of the asynchronous motor is arranged on the drive shaft of the Roots pump and is configured as a so-called cage rotor. This motor rotor has a relatively large mass and large axial overall length. Due to large unbalance forces of the motor rotor and the resulting vibrations, the drive shaft must be supported by at least one supporting bearing in the area of the drive motor. Cooling and lubrication of the supporting bearing or bearings are, in particular owing to the bearing arrangement in a gas-tightly sealed area of the vacuum pump, problematic and can be realized only at a high effort and expenditure.

As shown in DE-A-38 28 608, which represents the prior art, a vacuum rolling piston pump is driven by a synchronous motor. However, the configuration of

the motor rotor is not described. Synchronous motors are generally not suitable for use in vacuum pumps because the motor rotor is separately excited via heat-producing sliding contacts. A permanently excited synchronous motor rotor is unsuitable because it supplies, due to the constant rotor excitation, a constant torque which is maintained via the speed of the motor rotor, and overheating of the rotor may occur at higher speeds. Thus, in practice, synchronous motors are therefore not used for driving vacuum pumps.

SUMMARY OF THE INVENTION

The present disclosure provides a two-shaft vacuum pump with an improved drive motor.

The drive motor is a synchronous motor, wherein a rotor of the drive motor is configured such that it is permanently excited by a permanent magnet. The permanently excited rotor of the synchronous motor has a small mass and a small overall length due to a constantly strong magnetic field and a low power loss. As such, shaft support bearings for additionally supporting a drive shaft of the motor may be omitted, whereby the problems associated with cooling and lubrication of the support bearings are eliminated.

Due to the lower power loss in the permanently excited rotor, heating-up of the rotor and the problems associated with such heating-up are reduced.

The two-shaft vacuum pump of the present disclosure also includes a synchronous motor power-limiting means which limits motor power to a fixed maximum motor power in a limiting range above a fixed rated motor speed. The power-limiting means limits driving power to a constant value at a speed above the rated speed. This is effected by reduction of torque at a shaft speed above the rated speed.

The motor power results from the following equation:

$$P_M = M_M \times \omega,$$

where

$$\omega = 2\pi \cdot n,$$

P_M is the motor power,

M_M is the motor speed at speed n , and

n is the motor speed.

A speed reduction in the limiting range ensures that the two-shaft vacuum pump is capable of operating at high speeds of up to 8,000 revolutions per minute, but the pumping capacity is limited to a constant maximum value. The possibilities of dissipating a rolling piston heat are strongly restricted by the low gas pressure and the configuration of the rotor motor. By limiting the motor power and thus the pumping capacity without simultaneous speed limitation, overheating of the vacuum pump and, in particular, the rolling pistons is reliably prevented, wherein, at the same time, a high gas volume flow is maintained. In the limiting range, the synchronous motor is operated in a so-called field-weakening range.

A magnetic flux of the permanently magnetized motor rotor is constant such that a change in motor torque can be effected only by a corresponding control of a stator field.

In practical applications, permanently excited motor rotors have so far not been used in vacuum pumps. This is due to the torque, which is maintained constant over the overall speed range. This torque increases the danger of overheating of the motor rotor at high speeds which is caused by compression heat which increases with the speed. In view of these drawbacks, it has so far seemed unrealistic or impossible to use a permanently excited synchronous motor for driving a vacuum pump. However, the limitation of the motor power in the limiting range which is caused by a field-weakening

operation of a compression-induced heating of the motor rotor is limited to a constant value at higher speeds. This makes the use of a permanently excited synchronous motor possible and sensible, wherein the maximum torque of the motor can be used of until the limiting range has been reached.

According to one aspect of the present disclosure, the power-limiting means adjusts, in the limiting range, a phase angle between an electrical stator field and a magnetic field of the motor to an angle other than 90 degrees. The phase position of the electrical stator field is adjusted relative to the magnetic field of the rotor such that the torque is correspondingly reduced.

The power-limiting means can also reduce, in the limiting range, the amount of a stator current. This reduction of the stator current reduce a torque M_M which is proportional to the stator current.

According to another aspect of the present disclosure, the power-limiting means adjusts, in the limiting range, the phase angle and/or the stator current as a function of the motor speed. With increasing speed in the limiting range between a rated speed and a maximum speed, the phase angle and/or the stator current are changed such that the torque of the motor decreases with increasing speed to such an extent that the motor power above the rated speed is generally constant. Thus, the maximum permissible motor power is made available, but not exceeded, at each speed and the vacuum pump is protected against overheating.

According to yet another aspect of the present disclosure, a shaft comprising the motor rotor has an overhung configuration and is supported without a supporting bearing at the motor-side end. The shaft is supported by two main bearings arranged at two longitudinal ends of the rotor. As such, the structures required for cooling and lubricating the motor supporting bearings are omitted.

The motor rotor includes a plurality of permanent magnets arranged on an outside surface of a motor rotor body. It is also possible that at least one permanent magnet of the plurality of permanent magnets can be arranged in a recess located on the outside surface of the motor rotor body.

The motor rotor includes, in particular for operation with gases which may damage the motor, a rotor enclosure of a nonmagnetic material, which externally encloses the motor rotor body and the permanent magnets. Thus, the permanent magnets disposed on the outside surface of the motor rotor body are secured and protected against any aggressive gases and liquids and thus against corrosion. The rotor enclosure may be made from a nonmagnetic metal or a plastic material.

According to still yet another aspect of the present disclosure, a can is provided on the stator side, the can gas-tightly sealing the rotor towards the stator. The can is made from a nonmagnetic material or a plastic material. The can gas-tightly seals the pump area towards the surroundings, wherein the motor rotor lies within the pump area and the motor stator lies outside the pump area. Due to the use of a permanently excited synchronous motor, a gap between the rotor and the stator may be relatively large. This facilitates the insertion of the can.

According to still yet another aspect of the present disclosure, a pump cover holding the can and a stator casing surrounding the motor stator can be integrally formed. This configuration reduces the number of components and the number of joints of the two-shaft vacuum pump.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure may take physical form in certain parts and arrangements of parts, an embodiment of which will be described in detail in this specification and illustrated in the accompanying drawings which form a part of the disclosure. The description and drawings herein are merely

illustrative and various modifications and changes can be made to the component(s) and arrangement(s) of component(s) with departing from the spirit of the present disclosure. Like numerals refer to like components throughout the several view.

Fig. 1 shows a longitudinal cross-section of a two-shaft vacuum pump according to the present disclosure;

Fig. 2 shows a detail of a drive motor of the vacuum pump shown in Fig. 1; and

Fig. 3 shows a schematic representation showing motor power, motor torque, a pump moment characteristic curve, and a pumping capacity of the vacuum pump shown in Fig. 1 obtained with a 4.8 kW drive motor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

With reference to Fig. 1, a two-shaft vacuum pump 10 configured as a rolling-piston pump comprises first and second rotor shafts 12, 14. Each rotor shaft 12, 14 includes a pump rotor 16, 18 which is configured as a rolling piston. The second shaft 14 is driven by an electric drive motor 20, while the first shaft 12 is driven by a gear 24 formed by two toothed wheels 22, 23 and synchronized with the second rotor shaft 14.

The drive motor 20 is a synchronous motor and comprises a permanently excited motor rotor 26 and a motor stator 28 having a plurality of stator coils 30, 31.

The configuration of the motor rotor 26 is shown in an enlarged representation in Fig. 2. The motor rotor 26 includes a rotor body 34 provided on an outer circumference of the motor rotor. The rotor body can have a pot-shaped contour and is provided with a plurality of recesses 36 into

each of which a permanent magnet 38 can be secured. In one embodiment, the permanent magnet is made from rare earths elements. With permanent magnets of rare earth elements, strong magnetic fields of long duration can be realized at a small overall length. The permanent magnet is secured into the recess preferably by a conventional adhesive. The overall outer circumference of the rotor 26 is enclosed by a generally cylindrical rotor enclosure 40. The rotor enclosure 40 retains the permanent magnets 38 in the recesses 36 even at high rotor speeds and reliably shields the permanent magnets 38 against corrosion-developing gases and liquids. The rotor enclosure 40 is can be made from nonmagnetic high-grade steel. Although, as will be appreciated in accordance with the present disclosure, alternative materials including carbon fiber-reinforced plastic materials or other nonmagnetic materials can be used to form the rotor enclosure. The rotor body 34 can be a laminated or solid configuration. Between the rotor 26 and the stator 28, a can 42 is provided which is attached to a motor casing 44 on the stator side. The can 42 can have a pot-shape and gas-tightly seals the motor rotor 26 towards the stator 28. The can 42 typically is made from nonmagnetic high-grade steel, but can also be made from carbon fiber-reinforced plastic materials or other nonmagnetic materials.

Due to the drive motor's configuration as a synchronous motor rotor permanently excited by the permanent magnets 38, the motor rotor 26 has a generally small axial overall length and a generally small mass. This allows the second shaft 14 carrying the motor rotor 26 to be supported by two pump rotor rolling bearings 46, 47 alone and its motor-side end to be configured without a support bearing. As such, the motor rotor 26 has a cantilevered configuration.

The motor casing 44 has a one-piece configuration and includes a pump cover 48 holding the can 42 and a stator casing 50 surrounding the motor stator 28. The pump cover 48 holds the can 42 and gas-tightly seals a suction chamber 52 towards the outside. In a housing 54 placed on the outside of the motor

casing 44, a motor control 56 is accommodated. The motor control 56 controls the supply of the stator coils 30, 31.

The motor control 56 includes a synchronous motor power-limiting means 58 which, above a fixed rated motor speed n_N , limits motor power P_M to a fixed maximum motor power P_{Mmax} , as shown in Fig. 3. Thus, the maximum pumping capacity is limited to a maximum value. This is necessary to prevent overheating of the pump rotors 16, 18. The motor control 56 further includes a frequency converter (not shown) for starting up the drive motor and controlling the speed.

The motor power P_M results from the following equation:

$$P_M = \omega \cdot M_M,$$

where $\omega = 2\pi \cdot n$, n is speed of the motor, and M_M is the motor torque. At increasing speed, the motor power limitation can thus be effected only by reducing the motor torque M_M .

A speed range between the rated speed n_N , at which the maximum motor power P_{Mmax} is reached, and the maximum speed n_{max} is referred to as a limiting range. Since a magnetic flux generated by the permanently excited motor rotor 26 is always constant, a torque in the limiting range can be obtained only by correspondingly controlling the stator coils 30, 31. In the limiting range, the stator coils 30, 31 are controlled such that the torque is reduced with increasing speed and reciprocally proportional to the speed. In the limiting range, the drive motor 20 is operated in a so-called field-weakening range.

For this purpose, in the limiting range, the stator current is reduced in accordance with the necessary torque reduction. The power-limiting means 58 can adjust, in the limiting range, a phase angle between the magnetic field of the motor and an electrical stator field to an angle other than 90° . The

control of the motor current and/or the phase angle in the limiting range is always effected as a function of the motor speed.

With reference to Fig. 3, a pump torque M_p and the a pumping capacity P_p are generally below the motor torque M_M and the motor power P_M , respectively, due to at least friction losses. Overheating of the pump rotor is excluded when a maximum pumping capacity and motor power are correctly calculated and adjusted.

Although the present disclosure has been described and illustrated with reference to specific illustrative embodiments thereof, it is not intended that the disclosure be limited to those illustrative embodiments. Those skilled in the art will recognize that variations and modifications can be made without departing from the true scope of the invention as defined by the claims that follow. It is therefore intended to include within the disclosure all such variations and modifications as fall within the scope of the appended claims and equivalents thereof.